KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT

TECHNISCHE RAPPORTEN

T.R. - 54

C. Lemcke

Development of guidance forecasts at KNMI

2. Extreme windspeed IJmuiden

De Bilt, 1984

Publikatienummer: K.N.M.I. T.R. 54 (DM)

Koninklijk Nederlands Meteorologisch Instituut,
Dynamische Meteorologie,
Postbus 201,
3730 AE De Bilt,
Nederland.

U.D.C.: 551.509.313 :
551.509.322

Contents

1. Introduction

In the first report in the series "Development of guidance forecasts at KNMI" (Lemcke and Kruizinga, 1984) statistical methods, data sets and verification methods are described. In this second report the results are presented of our work on an objective method to forecast the extreme wind speed at IJmuiden (for definition see 2.1.). This station is used as a reference for the wind speed along the Dutch North Sea coast. Figure 1 shows the position of this station (1500 meter off shore). Experiments have been carried out both with the Perfect Prog (PP) and the Model Output Statistics (MOS) method. The MOS method was chosen for implementation in the operational guidance forecast, based on ECMWF products. Beside the point value of the extreme wind speed also the probability of three wind speed classes are forecast: less than six Beaufort, six or seven Beaufort or greater than 7 Beaufort.

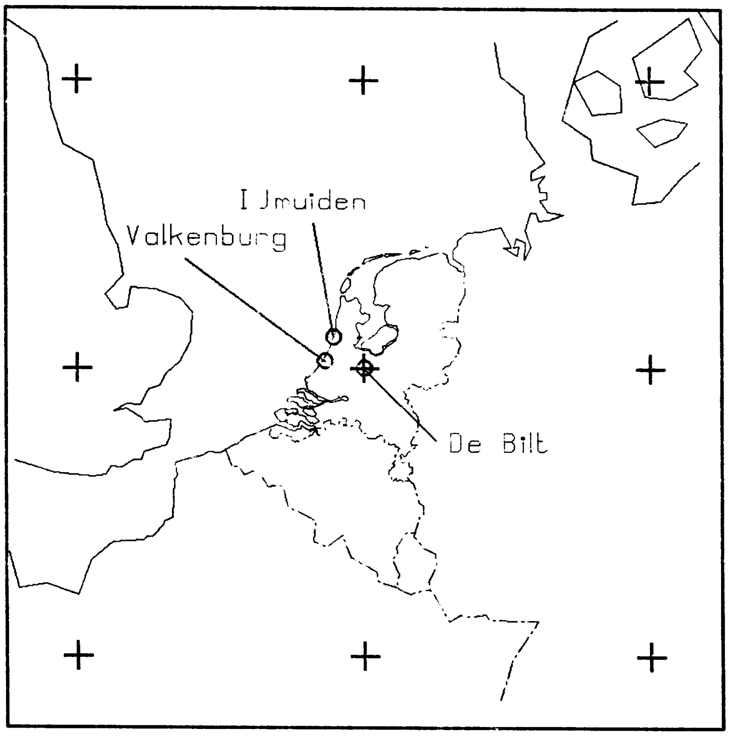


Fig. 1. Station IJmuiden and a part of the used grid.

2. Extreme wind speed at IJmuiden (06225)

2.1. Definition

The extreme wind speed at IJmuiden is defined as the maximum of the hourly wind speeds (measured at 18 m height, averaged over the last 10 minutes before observation time, as reported in the SYNOP-bulletins) during a period of 12 hours. The periods cover 18-06 GMT (night time) and 06-18 GMT (day time). We will indicate the maximum wind speed during night time by FX1806, during day time by FX0618 or in general by FX.

2.2. Climatology

The wind speed at IJmuiden has been measured at the present location -1500 meters off shore- since 1968. The data set we used was available on tape from January 1, 1971, until now. The period 1971 upto 1982 inclusive was used to compute the climatological values for each month and each pentad. The monthly mean values are presented in Table I for the periods 18-06 and 06-18 GMT. The anual mean maximum wind speed is about 19 knots (5 Beaufort), the peak occurs in November. The differences between day and night are small.

Table I. Monthly means of FX (knots) and of probabilities (%).
Period: 1971-1982.

	18-06 GMT											
month:	1	2	3	4	5	6	7	8	9	10	11	12
FX in knots	21	18	19	19	18	17	18	17	18	19	24	22
prob. FX > 6BFT	42	34	37	34	27	25	26	24	31	33	60	53
prob. FX > 8BFT	8	3	4	1	1	1	0	2	5	6	14	10

	06-18 GMT											
month:	1	2	3	4	5	6	7	8	9	10	11	12
FX in knots	21	18	20	20	18	18	19	18	19	19	24	23
prob. FX > 6BFT	45	31	41	38	32	28	28	29	33	36	62	53
prob. FX > 8BFT	7	3	6	2	1	1	1	2	5	5	16	12

Due to the relatively short period of twelve years it was necessary to smooth the pentad averages.

We applied the following filter 10 times:

$$\overline{FX} = (\overline{FX}_{p-2} + 2\overline{FX}_{p-1} + 3\overline{FX}_{p} + 2\overline{FX}_{p+1} + \overline{FX}_{p+2})/9;$$

p is the pentad number. These smoothed values are used for the calculation of skill scores relative to climatology. In Fig. 2 and Fig. 3 both smoothed and unsmoothed pentad averages of FX0618 are presented. (Climatology of FX1806 is similar).

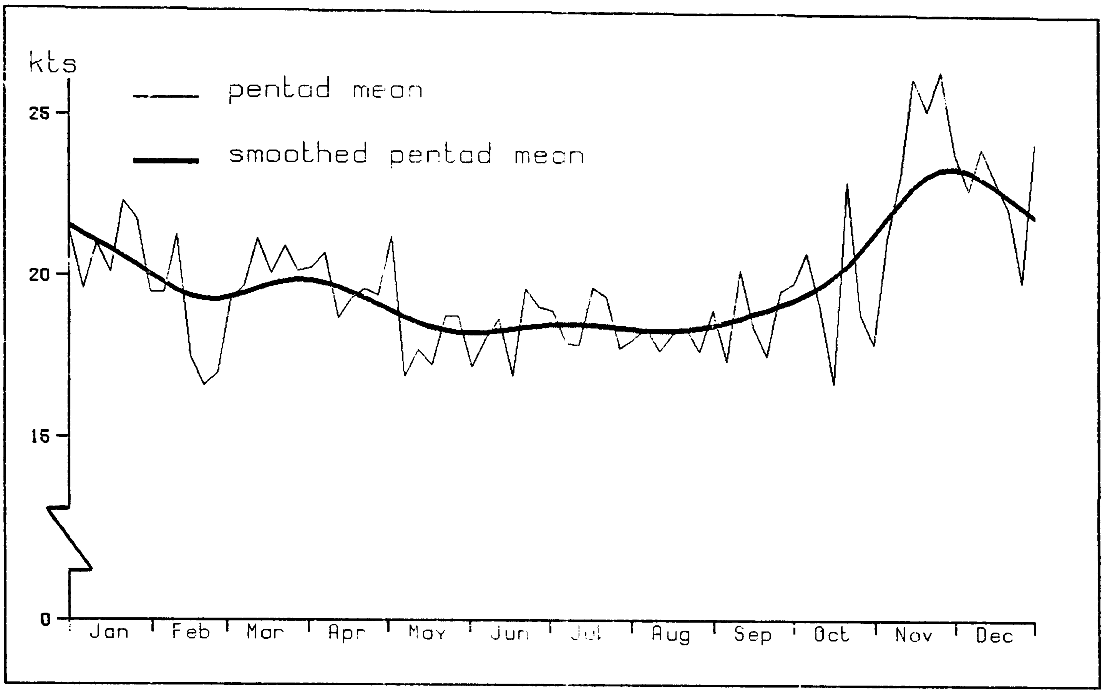


Fig.2. FX 0618, averaged over 1971-1982 for each pentad

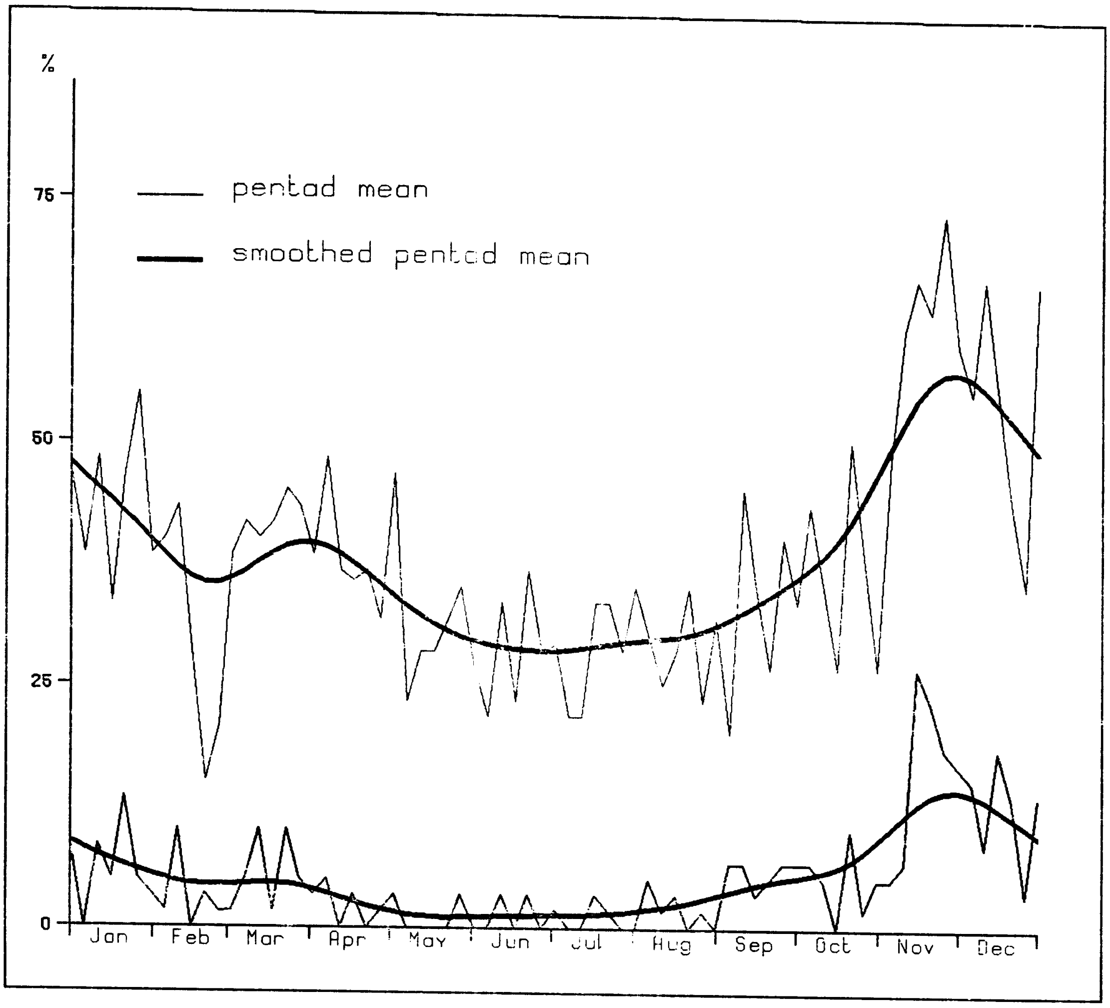


Fig.3. Probability of FX 0618 >= 6 Beaufort (above) and probability of FX 0618 >= 8 Beaufort (below), averaged over 1971-1982 for each pentad.

2.3. Data sets

The data sets in use for the development of the interpretation methods are described in Lemcke and Kruizinga (1984). For this experiment the following subsets have been used:

1. NCAR	12Z analyses 1000 and 5000 mbar geopotential height 1972-1979
2. ECMWF	00Z and 12Z analyses and prognoses 1000, 850 and 500 mbar height December 1, 1980 - November 30, 1983.
3. ANALOGUES	Dates of the selected analogues December 1, 1980 - November 30, 1983 based on ECMWF prognoses.

and of course the observed maximum wind speed as defined in 2.1. The geostrophic wind and other predictors are computed for grid point De Bilt. As illustrated in Figure 1, the distance between IJmuiden and De Bilt is very small compared to the spacing of the grid.

2.4. Methods

The experiments are carried out with analyses and forecasts verifying at 12 GMT. In the final stage equations have been derived for the night time period, using the 00 GMT products. Both Perfect Prog (PP) and Model Output Statistics (MOS) methods have been used, the latter with and without information extracted from "the analogues method" (Lemcke and Kruizinga, 1984).

The forecast equations for the point value of FX are derived with a standard multiple linear regression scheme:

$$FX = a_0 + \sum_n a_n x_n \, .$$

The x_n are variables (or predictors) forecast by the numerical model, the a_n are the coefficients which are to be derived.

For the probability of the three wind classes $\leqslant$ 5, 6 or 7, $\geqslant$ 8 Beaufort, the logit model (Brelsford and Jones, 1967) has been used.

Let P_1 = probability $FX \leq 5$ Beaufort,
P_2 = probability $6 \leq FX \leq 7$ Beaufort and
P_3 = probability $FX \geq 8$ Beaufort then

$$P_1 = \exp(fx1)/(1+\exp(fx1) + \exp(fx2))$$
$$P_2 = \exp(fx2)/(1+\exp(fx1) + \exp(fx2))$$
$$P_3 = 1 - (P_1 + P_2)$$

with $fx1 = b_o + \sum_n b_n x_n$

and $fx2 = c_o + \sum_n c_n x_n$.

Both schemes used the same predictors which were selected with a stepwise forward multiple regression scheme.

3. PP-experiments

3.1. Preliminary selection of predictors

In a preliminary experiment the Perfect Prog (PP) method has been used to determine which of the predictors of Table II were important. The geostrophic wind speed at 1000 mbar appeared to be by far the best predictor. In the eight year period 1971 up to 1979 inclusive the correlation between FX0618 and this geostrophic wind speed was 0.79, explained variance 62 percent. Some of the other 1000 mbar predictors played a role but none of 850 and 500 mbar predictors. The stability of the boundary layer is not used. We are mainly interested in higher values of the wind speed, in which case the stability plays a minor role. All further experiments were carried out with only 1000 mbar predictors.

Table II Preliminary set of predictors.

height	of 1000, 850 and 500 mbar
geostrophic wind speed	
vorticity	
relative vorticity advection	
coefficients 1, 2, 3, 4 and 5 of principal components of height field	

3.2. Seasonal dependency

Sometimes one can achieve better results by dividing the data set into two or more periods, for instance according to the four seasons. For each period separately an interpretation method has to be developed. For the maximum wind speed first a regression equation was developed for the year as whole and next for each season separately, using the data of 1972 up to 1979 inclusive. The two methods (one year-regression equation against four season-regression equations) were applied on the independent ECMWF data set of December 1980 up to November 1982 inclusive. The results of each season-method can be compared with the year-method. The results are shown in Table III.

As can be seen from this Table there are only negligible differences between the two methods and therefore the year-method has been chosen.

Table III Mean Absolute Error (MAE) FX0618 obtained with regression equations developed per season (S) and per year (Y) (PP method geowind 1000 mbar as only predictor, data set 1972/1979). Verified on independent data ECMWF December 1980/November 1982.

		forecast period						
		0	+24	+48	+72	+96	+120	+144
winter	S	3.93	4.33	5.01	5.77	6.19	7.09	7.24
	Y	4.01	4.58	5.30	5.92	6.56	7.39	7.46
spring	S	2.93	3.65	4.44	5.17	5.63	6.01	6.23
	Y	2.94	3.63	4.43	5.15	5.62	5.99	6.21
summer	S	2.90	3.14	3.66	3.94	4.32	4.52	4.97
	Y	3.09	3.23	3.67	3.98	4.30	4.59	5.01
autumn	S	3.40	4.19	5.01	5.61	5.97	7.21	6.90
	Y	3.46	4.05	4.84	5.36	5.68	6.79	6.52
year	S	3.29	3.82	4.52	5.11	5.52	6.20	6.34
	Y	3.37	3.89	4.58	5.12	5.57	6.17	6.27

3.3. Non-linear relation between maximum wind speed and geostrophic wind speed.

Malberg & Röder (1980) and Malberg & Frattesi (1983) found for the quotient q of surface wind speed to geostrophic wind speed V_g at Berlin a significant decrease with increasing geostrophic wind which could be described by a power function: $q = 1.08V_g^{-0.34}$. The period they used for their experiments coincided almost with the period of our PP-data set. We did a similar experiment with FX and the geostrophic wind. The data were averaged over classes with width of 5 knots, centered at 5, 10, 15 kts, etc. Only values of FX > 4 kts are used. In Table IV the mean value of q and standard deviation are presented.

Table IV Ratio FX0618/geowind, 12Z

class	number of cases	q	standard deviation q
5	373	2.24	0.78
10	684	1.59	0.45
15	605	1.30	0.31
20	426	1.16	0.25
25	279	1.03	0.19
30	169	0.96	0.19
35	74	0.90	0.16
40	46	0.87	0.14
45	28	0.85	0.10
50	10	0.65	0.18
55	2	0.80	0.03
60	3	0.74	0.08

The number of cases within the classes 50, 55 and 60 is small. Fitting all averages with a power function resulted in the equation
$q = 4.53V_g^{-0.45}$.

In Fig. 4 the values of q and the standard deviation are plotted, with the computed power function.

The q values for IJmuiden are much higher than those of Berlin, which can be explained by the fact that for IJmuiden the maximum wind was used, for Berlin the wind speed at 12 GMT. Beside this difference the influence of roughness and stability over land will be greater than over sea, resulting in lower q values over land.

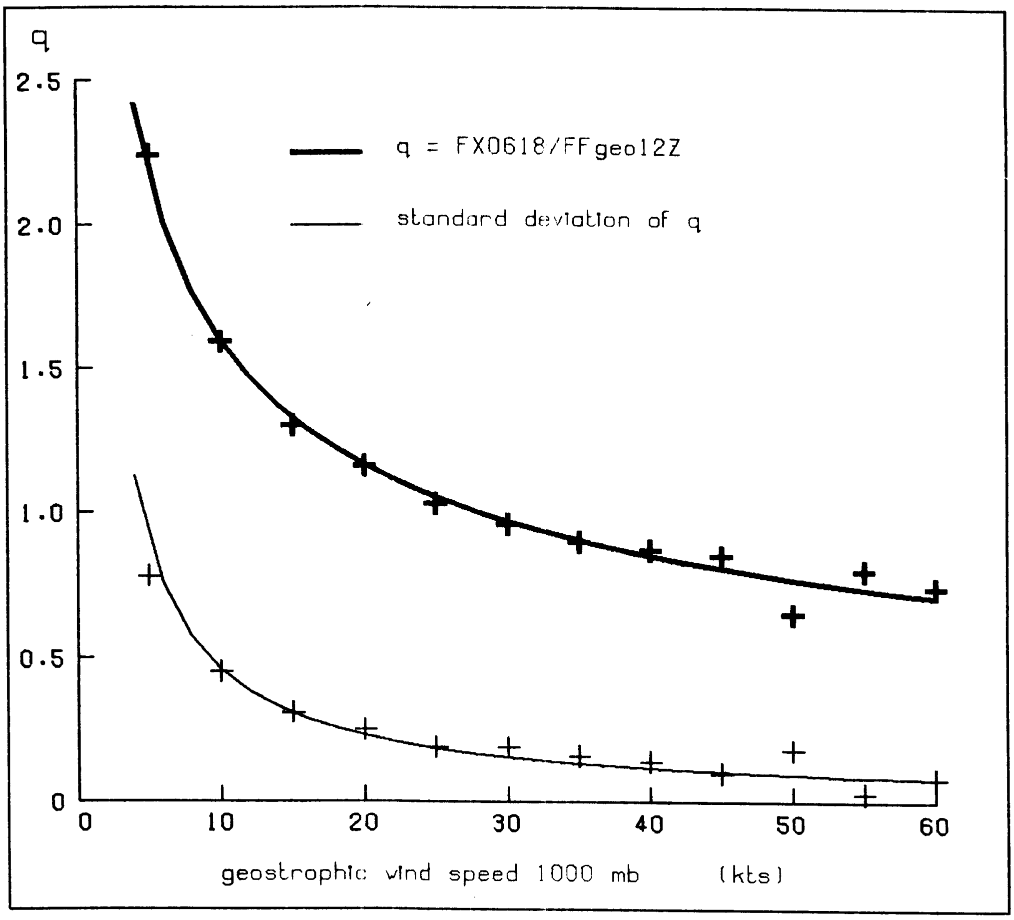


Fig.4. Ratio of the maximum wind speed 06-18 GMT and the geostrophic wind speed 12 GMT at 1000 mbar, averaged per class of 5 kts, with standard deviation and the corresponding power curves.

As can be seen the power curves fit almost perfectly. The relation is strongly non-linear for FX < 15 knots, however the standard deviation is high compared with the standard deviation for FX > 15 knots.
With the power function $q = FX/V_g = 4.53\ V_g^{-0.45}$ FX can be estimated provided that the geostrophic wind speed at 1000 mbar is known:
$FX = 4.53\ V_g^{0.55}$. The FX computed with this relation has been used as a predictor in the regression scheme. The results of this experiment are compared with the results of the first experiment, in which the 1000 mbar geowind itself was used as a predictor. As can be seen from Table V the geostrophic wind speed scores marginally better. The rest variances are 38.1% for the linear regression and 39.2% for the power curve. Therefore the power curve has not been used for the final regression equations.

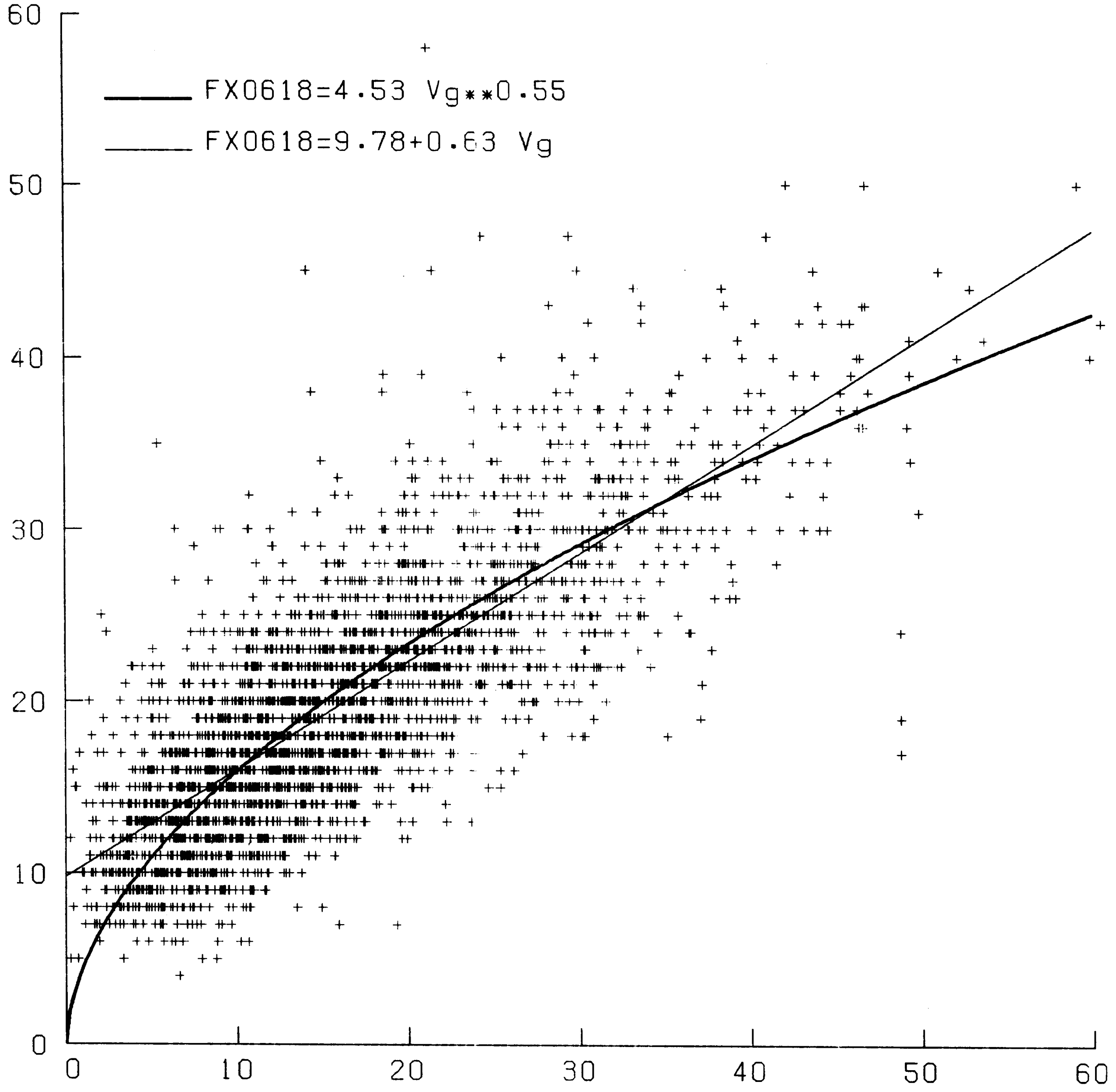


Fig.5. Geostrophic windspeed 1000 mb at 12 GMT versus the maximum wind speed 06-18 GMT with linear and power relation. Period: 1972-1979.

Table V MAE FX0618 with 1000 mbar geowind speed as predictor (I) and with FX from power function as predictor (II). (PP method, data set 1972/1979). Verified on independent data ECMWF 1980/1982.

	0	24	48	72	96	120	144
I	3.37	3.86	4.55	5.09	5.53	6.18	6.28
II	3.37	3.89	4.58	5.12	5.57	6.17	6.27

3.4. Additional 1000 mbar predictors

Further experiments were performed with the following potential predictors:

geostrophic wind speed at 1000 mbar
first three coefficients of the principal components of 1000 mbar height
class of 1000 mbar geostrophic wind direction (N, E, S or W)
sine of the day of the year
cosine of the day of the year.

The results of the PP method tested on the independent period December 1982 up to November 1983 inclusive are presented in Table VI. For lead times longer than 72 hours the PP method is worse than the result obtained by using the climatological value of FX as forecast.

4. MOS-method

The data set with ECMWF analyses and forecasts starts in December 1980. The first two years of this set have been used to develop equations based on MOS, the data after November 1982 as independent test set. With the same predictors as used for the PP method regression equations have been derived for FX0618 for each time step. It is clear from Table VI that the MOS approach performs much better than the PP-method. Up to +144 hours the skill with respect to climatology is positive.

4.1. The use of output of the analogue method as a predictor

From experiments with information extracted from the analogues method (Lemcke and Kruizinga, 1984) as a predictor in the MOS scheme for the probability of precipitation (Kruizinga, 1983) it appeared that such information could be very useful. Therefore we decided to do an experiment with analogues input. However, the analogue-method requires wind speed observations during a 30 years period, which was not available for IJmuiden. Therefore the observations of Valkenburg (06210) were used instead. The data of station Valkenburg appeared useful, although Valkenburg has the characteristics of a land station and although the data before 25-4-1962 are not reliable. Empirically it was found that the percentage of analogues with a wind speed $\geqslant$ 5 Beaufort at Valkenburg is the best analogues predictor. This predictor was selected for all lead times, as depicted in Table VII. For lead times up to +84 hours the geostrophic wind speed was selected first, thereafter the analogues predictor was chosen as first one.

Table VI MAE FX0618, dependent data: December 1980/November 1982, verified on December 1982 up to November 1983 inclusive.

method	24	48	72	96	120	144	climatology
PP 72/79	4.13	4.98	5.35	5.96	6.28	6.53	5.95
MOS without analogues	4.08	4.74	5.02	5.35	5.42	5.61	
MOS with analogues	3.98	4.57	4.92	5.25	5.45	5.66	

The results for the +120 and +144 hour prognoses are not better with than without analogues. However, the analogues-method has been used for almost 10 years for the probability of precipitation, maximum and minimum temperature and sunshine. It has proved to be a stable method during these years and therefore we can expect the regression equations to be more stable by using the analogue-predictor. The analogues are selected for the lead times +24, +48, +72, +96, +120 and +144. From each set of analogues the analogues predictor for both the period 18-06 and 06-18 GMT is computed; we did not have selected analogues for the lead times +12, +36, ..., +132 in our data base.

4.2. Final selection of predictors

The final regression equations, both for 18-06 GMT and 06-18 GMT have been derived with the predictors described before. In Table VII the selected predictors for each lead time are presented.

Table VII Selected predictors with order of selection

set of predictors	verifying time													
	H-012	H+000	H+012	H+024	H+036	H+048	H+060	H+072	H+084	H+096	H+108	H+120	H+132	H+144
first coefficient of 1000 mb principle components	5	5	6	6	6		6		4	4	4			
second coefficient of 1000 mb principle components														
third coefficient of 1000 mb principle components	2	2	2	2	2	3	3	3		3	3	2	3	3
geostrophic wind speed of 1000 mb	1	1	1	1	1	1	1	1	1	2	2	3	2	2
wind direction between 315 and 45 degrees					7									
wind direction between 45 and 135 degrees							4							
wind direction between 135 and 225 degrees	3	4	3	5	5		5		5					
sine of the day of the year														
cosine of the day of the year	4	3	4	4	4	4	4		3		5			
analogues			5	3	3	2	2	2	2	1	1	1	1	1

Note: no analogues are available for the analyses.

The same selected predictors are used to predict the probability of FX ⩽ 5 Beaufort, FX = 6 or 7 Beaufort or FX ⩾ 8 Beaufort.

5. Verification results

Both the point value forecast and the probability forecast have been verified over the period December 1982 up to November 1983 inclusive. For the point forecast the Mean Absolute Error (MAE) has been used as before, for the probability forecasts the Ranked Probability Score (RPS) was used (Epstein, 1969; Daan and Murphy, 1982). The results are presented in Table VIII. Lower values indicate better forecasts. We can convert both types of scores into a skill related to climatology

$$\text{skill} = \frac{\text{score (climatology)} - \text{score (forecast)}}{\text{score (climatology)}} \times 100.$$

Forecasts with a RPS or MAE higher than or equal to climatology result in a skill $\leqslant 0$, the maximum skill is 100. A better forecast results now a higher value of the skill. In Table IX the results of Table VIII are presented as skills. The skills are positive up to H+144 inclusive.

Table VIII Mean Absolute Error (MAE) of the point value forecast of FX and the Ranked Probability Score (RPS) of the probability forecast of FX, with the predictors from Table VI.

Independent test period December 1982 up to November 1983 inclusive.

	verifying time											
	12	24	36	48	60	72	84	96	108	120	132	144
MAE point value forecast (kts)	3.8	4.0	4.4	4.6	4.9	4.9	5.2	5.3	5.4	5.5	5.8	5.7
RPS probability forecast	.17	.19	.21	.23	.24	.25	.26	.26	.26	.27	.28	.29

Table IX The MAE and RPS of Table VIII converted to skill scores with respect to climatology.

	verifying time											
	12	24	36	48	60	72	84	96	108	120	132	144
MAE skill score (%)	41	33	31	23	24	17	19	12	16	9	10	5
RPS skill score (%)	48	41	38	31	27	24	22	22	21	17	14	13

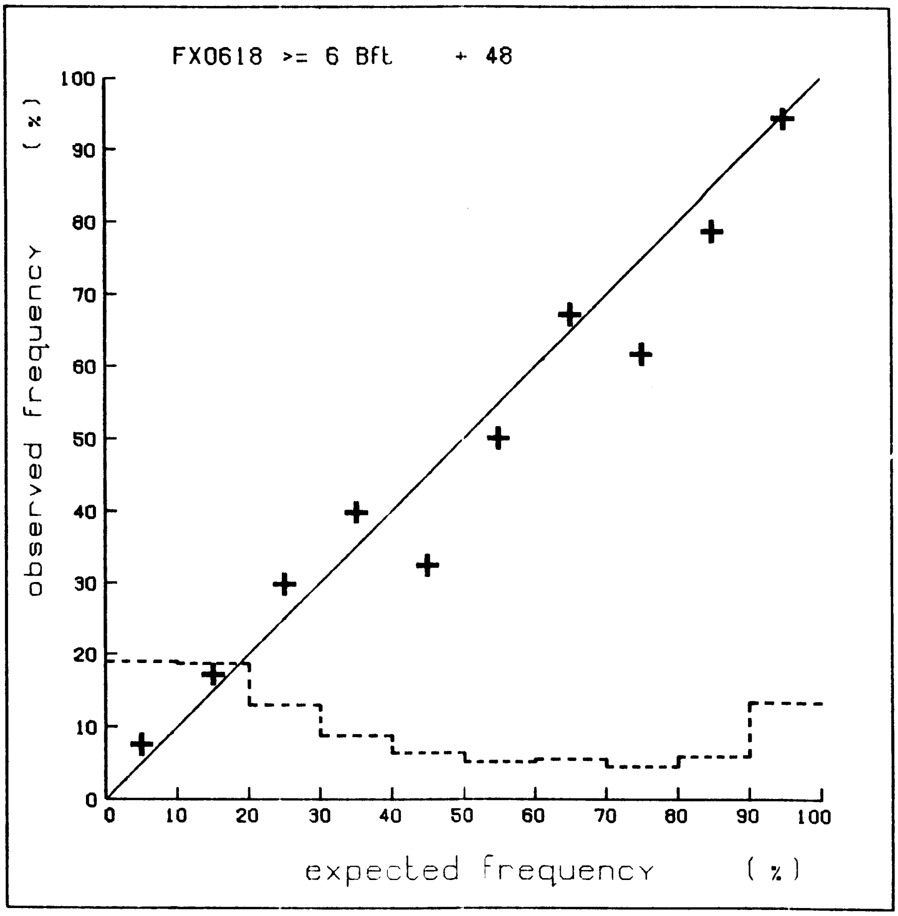
Apart from the skill the reliability of probabilistic forecasts is important. Reliability means that after a set of forecast "the probability of FX $\geqslant$ 8 Beaufort is p%" the event must have occurred in p% of the cases. For this kind of verification it is necessary to use a large number of data, therefore both dependent and independent data are used to produce reliability diagrams. We defined 10 classes, the first class contained all forecasts of probabilities between 0 and 10%, the second class all forecasts from 10 to 20% etc. The relative frequency of occurrence of the event after a forecast in a given group is plotted versus the midpoint of the intervals. For reliable forecasts this relative frequency is expected near to this midpoint. For the ideal reliability the plots should be on the straight line through (0, 0) and (100, 100). In Fig. 6 and Fig. 7 the observed frequency of occurrence in each class is plotted against the expected frequencies. The relative number of forecasts is also indicated. However, reliability can also be interpreted as a part of the Brier-Score (Daan and Murphy, 1982). In terms of the diagram the reliability defined by Murphy is the weighted average of the squared vertical distances between the plotted points and the diagonal. The weights must be chosen equal to the number of forecasts associated with the plotted points. The reliability RLB can be found by $RLB = \frac{1}{N} \sum_{s=1}^{S} N_s(O_s - P_s)^2$ in which is N the total number of forecasts, N_s the number of forecasts in each interval, S the number of intervals, P_s the midpoint of the interval and O_s the observed frequency in the interval. In the ideal case RLB will be zero. In practice the expected RLB of reliable forecast depends strongly on the total number of forecast. For the 10 intervals described above it can be shown (Lemcke and Kruizinga, 1984) that the expected RLB for reliable forecasts is : E(RLB) = 16750/N (O_s and P_s in percents). In table X the expected RLB and the computed RLB are presented.

Table X Reliabilites. Period: December 1980 up to November 1983 inclusive.

	-12	0	12	24	36	48	60	72	84	96	108	120	132	144
RLB FX ≥ 6 Bft	13.6	33.0	16.4	26.5	15.5	29.4	13.5	27.8	20.2	14.1	14.4	23.3	12.0	9.8
E(RLB) FX ≥ 6 Bft	20.1	15.8	17.1	17.3	17.1	17.3	17.2	17.4	17.2	17.4	17.3	17.3	17.3	17.6
RLB/E(RLB)	0.68	2.09	0.96	1.53	0.91	1.70	0.78	1.60	1.17	0.81	0.83	1.35	0.69	0.56
RLB FX ≥ 8 Bft	30.3	38.1	39.8	57.5	17.8	25.0	17.0	20.2	42.4	13.2	14.8	10.9	23.5	7.4
E(RLB) FX ≥ 8 Bft	20.1	15.8	17.1	17.3	17.1	17.3	17.2	17.4	17.2	17.4	17.3	17.3	17.3	17.6
RLB/E(RLB)	1.51	2.41	2.33	3.32	1.04	1.45	0.99	1.16	2.47	0.76	0.86	0.63	1.36	0.42
number of cases	833	1061	979	970	977	968	972	964	972	965	969	969	971	954

It can be shown that in case with 10 intervals the forecasts are reliable if the ratio of the computed reliability and estimated reliability is in the range 0.39 → 1.83.

From Table X we can conclude that the probability forecasts generally speaking are reliable.



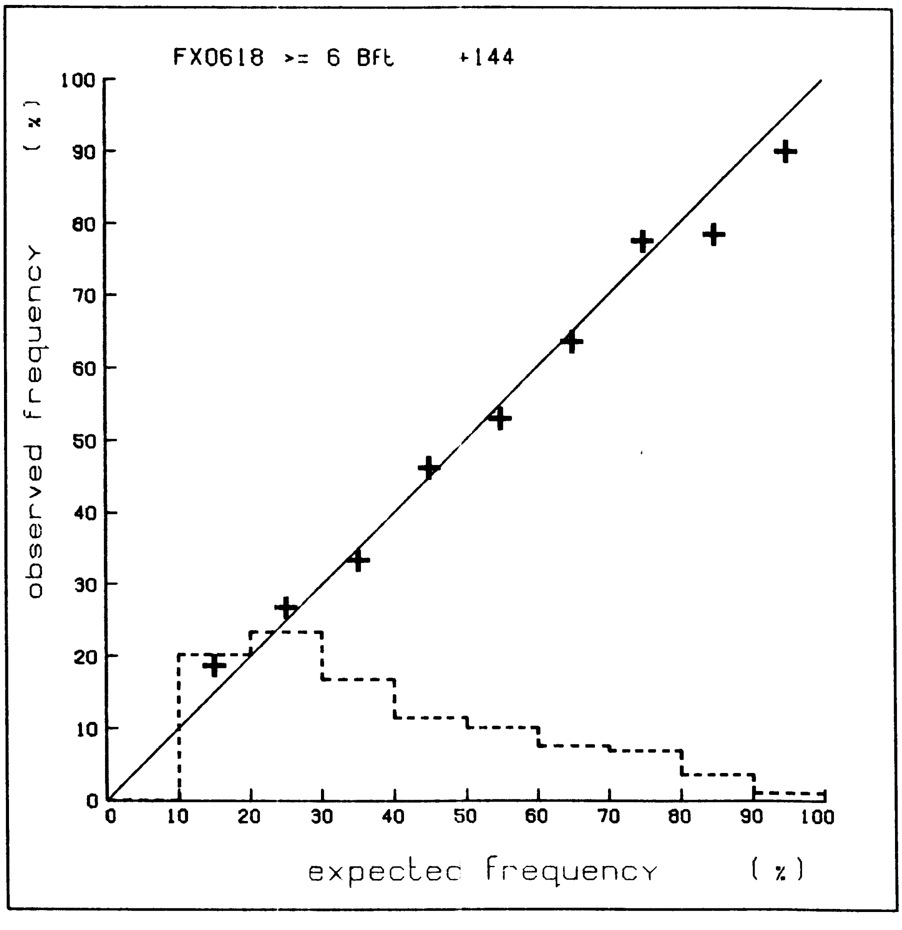
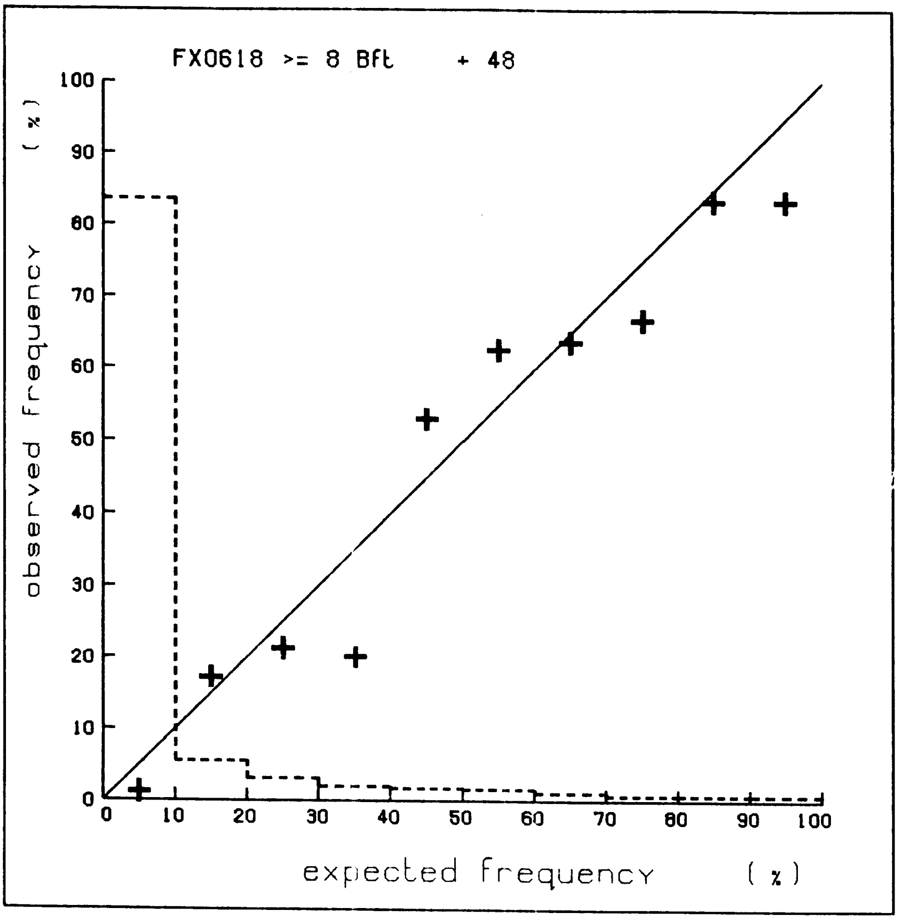


Fig.6. Reliability diagram probability forecast FX.
Period: December 1980 / November 1983.
-------- Percentage of total number of forecasts.



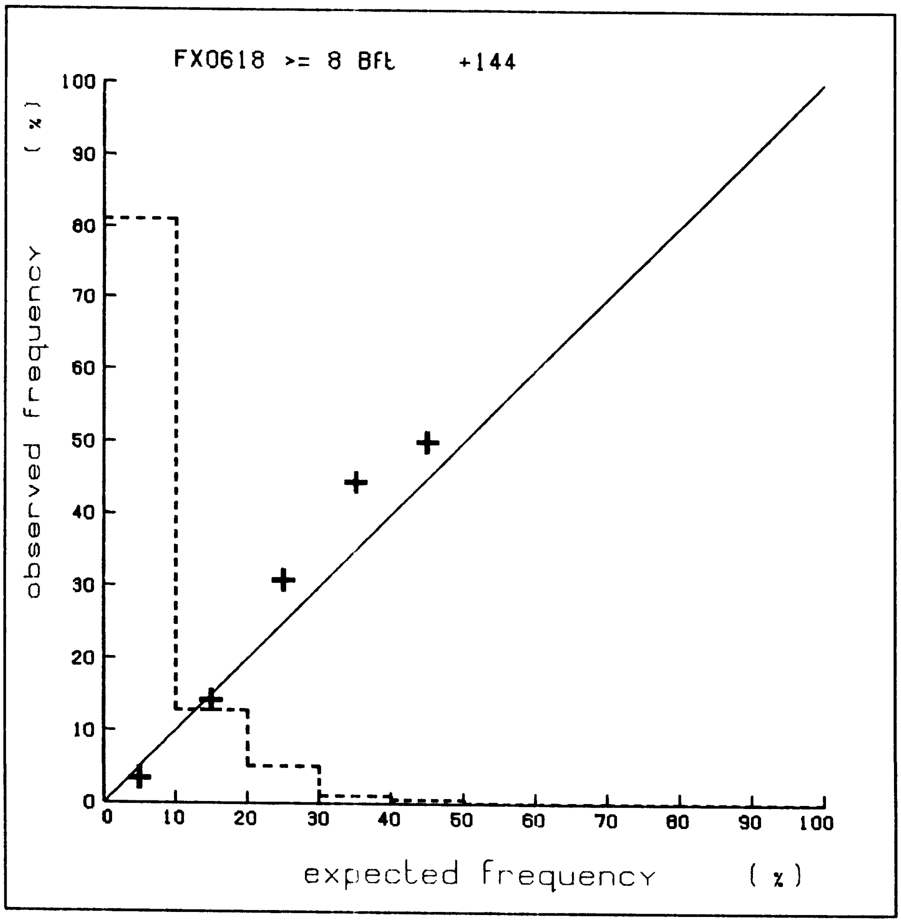


Fig. 7. Reliability diagram probability forecast FX.
Period: December 1980 / November 1983.
-------- Percentage of total number of forecasts.

6. Conclusions

The maximum wind speed within a twelve hour period can be predicted both as point value and as probability forecast with positive result up to H+144 inclusive. The MOS method is better than the PP method. Information obtained from the analogues-method improves the interpretation marginally but can be useful by stabilizing the forecasts equations.

7. Literature

Brelsford, W.M. and R.H. Jones, 1967: Estimating probabilities. Monthly Weather Review Vol. 95, No. 8, 570-576.

Daan, H. and A.H. Murphy, 1982: Subjective probability forecasting in The Netherlands: Some operational and experimental results. Meteorol. Rdschr. 35, 99-112 (August 1982).

Epstein, E.S., 1969: A scoring system for probability forecasts or ranked categories. J. Appl. Meteorol., 8, 985-987.

Kruizinga, S., 1983: Statistical Medium Range Forecasting of the Probability of Precipitation in The Netherlands. Eight Conference on probability and statistics in Atmospheric Sciences, November 16-18, 1983, Hot Springs, Arkansas.

Lemcke, C. and S. Kruizinga, 1984: Development of guidance forecasts at KNMI (1) - general information. KNMI Technical Report TR-54, 1984.

Malberg, H. and W. Röder, (1980): Über den Zusammenhang zwischen Bodenwind und geostrophischem Wind sowie die empirische Bestimmung des Reibungskoëffizienten. Meteorol. Rdschr. 33, 161-167 (Dezember 1980).

Malberg H. and G. Frattesi, 1983: Objektive Windvorhersage auf der Basis des geostrophischen Windes. Meteorol. Rdschr. 36, 20-24 (Februar 1983).

National Weather Service, 1983: The use of model output statistics for predicting surface wind. Technical procedure bulletin 335, September 1983, U.S. Department of commerce.

Wieringa, J. and P.J.M. van der Veer, 1976: Nederlandse Windstations 1971-1974. KNMI Verslag V-278. In Dutch.